Thermal imaging of railroad cars used for molten iron transport

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ABSTRACT

The primary production of steel in integrated mills commonly uses Pugh-type railroad cars to transport molten iron from the Blast Furnace process to the Basic Oxygen Furnace process. Thermal imaging and analysis can be used to monitor the condition of the refractory within these railroad cars. This results in the avoidance of molten metal breakouts on the cars and the maximization of the refractory campaign life. An additional benefit is the significant savings on the maintenance costs of this equipment and greater production efficiencies through planned maintenance practices.

These railroad cars are football shaped with an opening at the top and are commonly known as "subs" or "bottle cars" in the steel industry. The shell of the vessel serves as both the reservoir for the molten metal and as the structural frame of the car. The interior of the shell is typically lined with ceramic refractory. Periodic applications of gunnite material maintain the integrity of the refractory. Other combinations of materials are also used within the shells of these cars to provide an insulating barrier between the molten iron and the steel shell.

In the past these cars were pulled from service for maintenance inspection and repair based on the tons of metal passed through the car during normal production. The refractory condition could not be assessed until the car had cooled down enough for an internal visual inspection.

Thermal imaging equipment is now being used to monitor the radiated heat from the shells of these railroad cars to assess the need for maintenance. High and low temperatures are recorded in several different areas of the vessel and are compared with benchmarks developed through several years of measurements and experience. Not only is the hottest temperature of the shell important but also the difference between this and the coldest temperature on the shell. The hottest temperature gives an indication of the thickness of the refractory in a certain area. The difference between the hottest and coldest temperatures gives an indication as to the amount of thermal growth induced stress the shell is exposed to. When the shell temperatures breach the established limits, the car is pulled from service for inspection and refractory lining maintenance.

The planning and efficiency of refractory lining maintenance is greatly improved through a well established thermographic monitoring program. Problems that arise earlier than anticipated are quickly noted and rectified, avoiding the cost of product loss and equipment repair or replacement. Refractories that last longer than expected may be left in service to maximize the campaign life of those linings.

Keywords: infrared, thermal imaging, bottle cars, subs, molten iron, ceramic refractory, ladle cars

1. Introduction

Integrated steel mills commonly use the blast furnace process to convert raw pelletized forms of iron ore from a solid state to a molten state. A single blast furnace may produce from 1,000 to 10,000 tons of molten iron per day depending on the furnace size and design and can operate continuously 24 hours a day, seven days a week. Integrated steel mills commonly have two or more blast furnaces operating in tandem. The molten iron is typically transported from the blast furnace process to a basic oxygen furnace process where the appropriate alloy for a customer's application is produced. The distance between these two processes can vary from a few hundred yards to several miles depending on the layout of the specific integrated steel mill.

1.1. Transportation of Molten Iron

The transportation of the molten iron, which is usually above 2500°F, is commonly accomplished by railroad car *(see image 1)*. The railroad car is technically referred to as a Pugh-type ladle and is also commonly referred to as a bottle car , ladle car, torpedo car or sub. The ladle is football shaped with an opening at the top. It has a capacity of up to 200 tons. The steel shell itself serves as the structural frame of the railroad car with both ends resting on a railroad truck. The steel shell is lined with refractory. The ladle is emptied by rotating it about its longitudinal axis. These railroad cars are commonly filled and emptied several times per day. The filling and emptying causes erosional wear from the molten iron and slag entering and departing the refractory lining as well as thermal cycling from exposure to above 2500°F molten iron and then ambient temperature air which can range from 120°F in summer time to -20°F in winter time. If the refractory lining integrity within the shell fails and molten iron contacts the steel shell it will quickly fail allowing molten iron to spill.

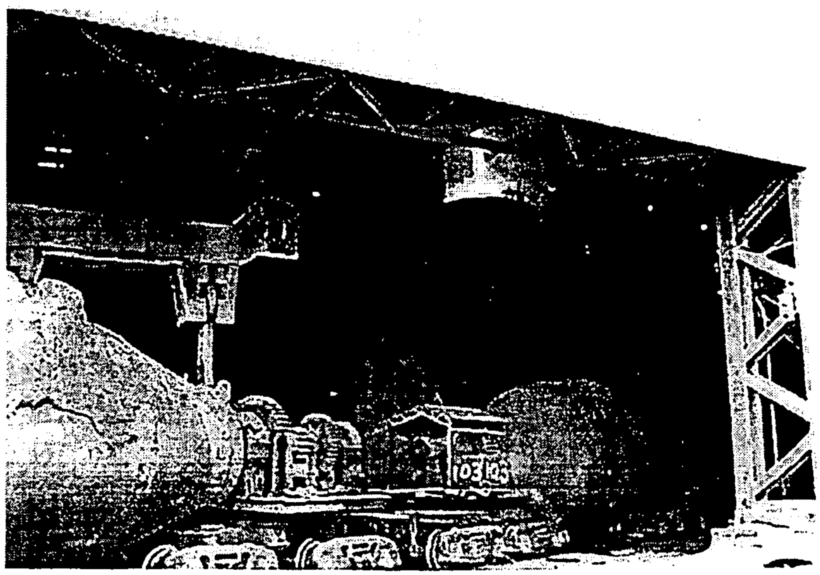


Image 1: Pugh-type molten iron railroad car

1.2. Costs related to spills

The occurrence of a spill can be extremely costly to a company. The value of the molten iron spilled can conservatively range from $10,000 to $40,000 depending on the car capacity and current market value. The damage to the railroad car can cost several hundred thousand dollars to repair and can require complete replacement. If the spill damages a critical point on the railroad track the transportation of any molten iron may be halted for several hours until the railroad car can be removed and the track repaired. The stopping of production can conservatively cost between $10,000 to $50,000 dollars per hour depending on the size of the blast furnaces that are losing production. The point to be made is a small leak can cost a company several hundred thousand dollars and very likely much more. *(see image 2)*

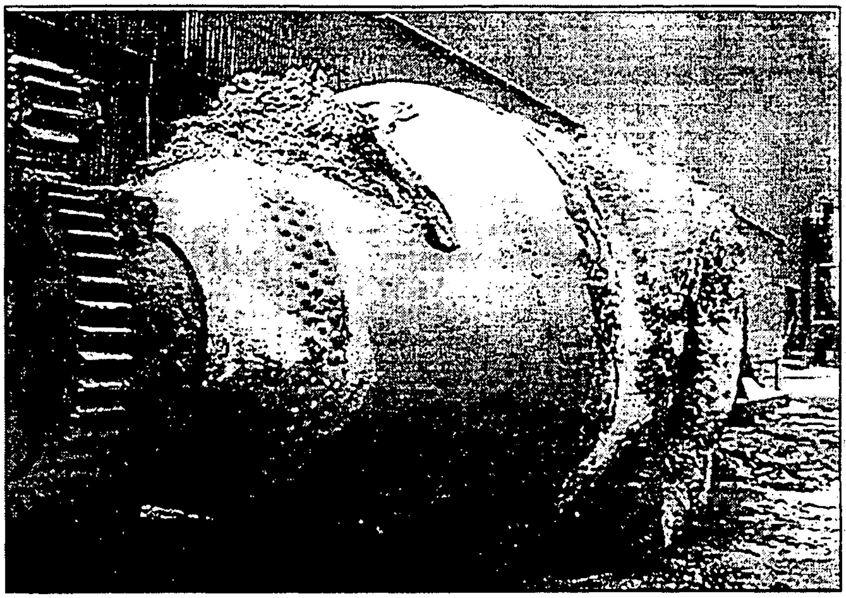


Image 2: Pugh-type molten iron railroad car after metal breakout

2. Control of Refractory Lining Wear

The control of the integrity of refractory linings within the shells is a large responsibility. The cost of the material and the installation of linings is very expensive. The goal is prevention of lining breaches that cause a metal breakout or leak and maximization of the life or campaign of the lining.

2.1. Conventional methods of preventive maintenance

Typically the life of a lining is measured by the quantity, or tons, of molten iron passed over the lining. If a specific railroad car has a 150 ton capacity and is filled and emptied three times during a 24 hour period the total quantity would be 450 tons for that day. In the past a railroad car would be taken out of service for a visual inspection of the lining after a fixed number of tons. The lining would take several days to cool down before any inspection or repairs could take place and after repairs were complete the lining would need preheating for several days before entering back into service. This requires a significant number of extra railroad cars over and above normal production needs to accommodate for times when several railroad cars are out of service for inspection and repair. These extra railroad cars represent a significant capital investment.

2.2. Use of Infrared Imaging Equipment

Infrared imaging has been used for several years to analyze the condition of the refractory linings in these railroad cars *(see image 3)*. Infrared survey programs have provided steel makers with valuable information that aids in decisions as to when to pull a railroad car out of service for inspection. This helps maximize the utilization of a lining that is maintaining its integrity. The railroad car can be left in service longer without a total cool down for visual inspection. The total cool down itself damages the lining through thermal cycling. If a hot spot is detected early in a campaign the car can be pulled for inspection before further lining damage or a breakout occurs. Ultimately the railroad cars can be left in service until their condition warrants an inspection. This early warning information allows the maintenance manager much more flexibility in scheduling work on the railroad cars.

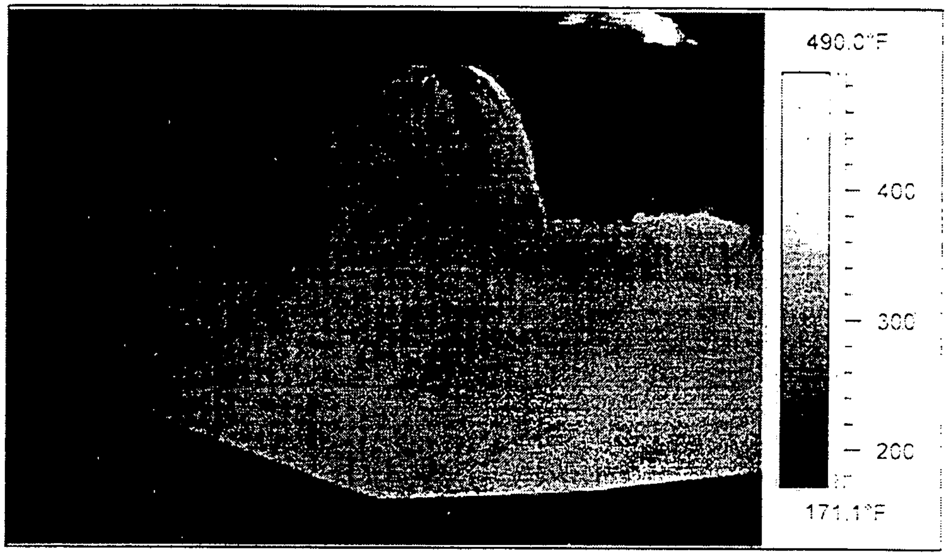


Image 3: Infrared Image of a Molten Metal Railroad Car

3. Infrared Survey Program

This section discusses the use of an AGEMA 550 infrared camera with a 40° wide angle lens. Other cameras can be used for this purpose provided a similar lens and temperature measurement capabilities up to at least 1000°F are available. The surface of the shell is a heavily oxidized steel thus an emissivity setting of 0.90 to 0.95 is generally used.

3.1. Taking an optimum image

The shape of the railroad cars is such that taking images to perform an accurate analysis of the surface temperatures can be challenging. A surface within 60° of perpendicular to the camera should exhibit 98% of optimum emissivity. Generally the railroad cars have a barrel shaped body with a cone on both ends. Taking two images of each side helps maximize the amount of surface area within 60° of perpendicular to the camera. The image is taken from a distance of approximately 5 meters. Maximum accuracy is achieved when the image is taken from a point which bisects the angle created by the transition from the cone to the body. *(see image 4)*.

Image 4: Acquiring the optimum image.

3.2. Recording and analyzing the images

While collecting images the orientation is noted in relation to the end of the car with the drive used for rotating the vessel for dumping. Each image of the shell is divided into five subsections for analysis. These subsections are identified as the mouth area, body, top of the cone, bottom of the cone, and the nose. *(see illustration 5)*. Image 4 on the previous page shows a thermographer in the ideal position relative to the railroad car for acquiring an image of the drive end of the car.

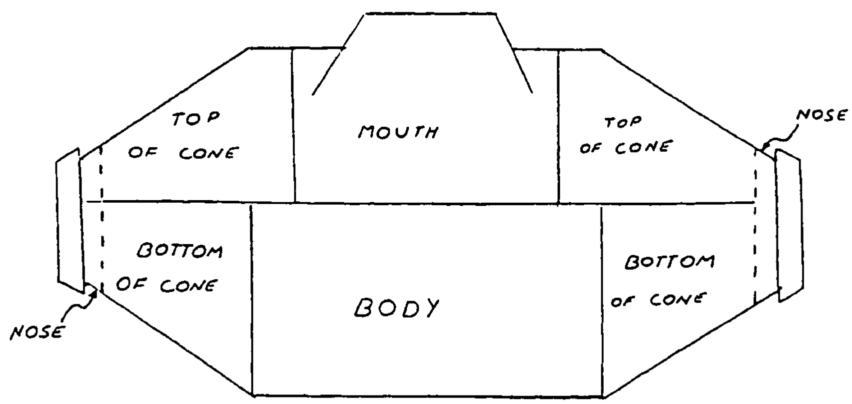


Illustration 5: Subsections of a car image

The images are analyzed to determine the hottest point within each subsection. The temperatures found in the mouth area are generally disregarded because they may be misleadingly hot due to spills of molten iron and exposure to the radiant energy of the molten iron during filling and emptying. Only in rare cases when a very apparent thermal pattern forms showing definite refractory degradation is a temperature in the mouth area significant. The main areas of concern are the body and cone areas. The highest temperatures are recorded for each subsection of each image of the shell. The temperature in the nose area is referred to as the minimum temperature for that specific image of the shell. The nose area is the coldest section of the shell because it is entirely filled with refractory. The temperature found on the shell is used to give an indication of the condition of the refractory lining. The difference between the hottest temperature on the car and the coldest temperature is the delta temperature which represents the relative stress induced on the steel shell. Through experience and open communications with the maintenance people responsible for these railroad cars, a set of limits has been derived for reliable operation. The following is a list of the conditions and the recommended action associated with each;

CONDITION	ACTION
The high temp is less than 600° F and the delta temp is less than 250° F:	No Action
The high temp is greater than 600° F:	Remove from Service
The high temp is greater than 500° F & the delta temp is greater than 250° F:	Remove from Service

The above is presented only as an example of how this information may be used to help in evaluating the condition of the lining in these railroad cars. The type of refractory and thickness as well as shell design may dictate different limits for reliable performance. One method for establishing limits is the trending of temperatures over time for each subsection coupled with visual inspection of the refractory lining after pulling from service to establish a relationship between the refractory thickness and apparent shell temperatures.

3.3 Specific situations

A familiarity with the steel making process is valuable for understanding some additional influences on the apparent surface temperatures measured with the camera. The car should be full of molten iron, the outside of the shell should be free of any foreign debris and the image acquired moments before the car is emptied at the Basic Oxygen Furnace. Not all of these conditions are controllable and familiarity with the process allows one to make judgements in the field about the validity of acquired images.

Occasionally a car is overfilled at the blast furnace and molten iron spills over onto the ground and is still transported to the basic oxygen furnace. This can cause several problems related to acquiring and analyzing images. Some of the metal and slag will freeze on the shell of the car and create an additional thermal barrier. This thermal barrier hides the damage caused by the initial contact of the molten iron on the shell. Another problem can be a hot spot created on the bottom of the body from the puddle of molten iron radiating upward. This puddle can effect not only the railroad car that was overfilled but other railroad cars located on parallel tracks. Once the car is transported to the Basic Oxygen Furnace the thermographer finds an apparent hot spot on the body which is well above the established limits of the program. Experience and process familiarity help the thermographer assess all aspects of a situation before reporting an apparently serious problem that may not be. If a spill was found to have occurred, the best bet is to wait until the car has been emptied and filled again before acquiring an image. This usually takes several hours.

Once a car has been emptied a common practice is to throw an insulating blanket over the mouth of the car to retain as much heat as possible, since this saves both thermal energy and minimizes the damaging thermal cycling on the refractory. The blanket is sometimes blown off the mouth during the filling process at the blast furnace and a portion of it falls on the top of the cone. The blanket acts as an additional thermal barrier which prevents accurate temperature readings. However if the blanket falls off the car shortly before the thermographer arrives it will leave an apparent hot spot on the shell of the car. This is difficult to diagnose but if the area is suspicious waiting approximately an hour will allow the area to return to a relatively steady state condition.

During rainy weather the cooling effect of the water makes the images very unrepresentative of the condition of the refractory. The shell temperatures tends to be at or below the boiling point of water. If the ambient temperature is below freezing and the wind is blowing, which is common in northern steel mills, the apparent shell temperatures can be reduced by up to 100° F. Minimal wind, dry weather, and ambient temperatures above freezing provide consistent reliable results.

When acquiring images while inside a basic oxygen furnace there are several other heat sources well over 500° F and up to 2900° F that can cause reflections even on oxidized steel. The thermographer needs to be aware of these and their influences. One specific area to stay away from is when a railroad car is staged over the area called the hot metal hole. A cup shaped ladle is placed in the hole and the railroad car is rotated to empty it's contents into the ladle. When acquiring an image from across the ladle the radiated heat from the refractory in the empty ladle is well over 2000° F and causes a severe thermal reflection on the railroad car.

3.4. Reporting

The use of reporting for the customer is generally dictated by specific needs. However a sample report is included as the final page *(see image 6)* to suggest a means for conveying the results of image analysis.

4. Summary & Conclusions

Integrated steel producers implement vast amounts of capital equipment to produce large quantities of steel for their customers. If railroad cars are used for transportation of the molten iron from the blast furnace to the basic oxygen furnace the potential for large financial losses is present. Thermal imaging equipment can be effectively used to minimize risk and save money in relining costs. The development of a successful program requires open communications between the thermographer and the maintenance staff. The application of the principles presented in this paper may also be used in other refractory lined systems as well. One such application is a blast furnace which possesses several subsystems requiring periodic refractory maintenance.

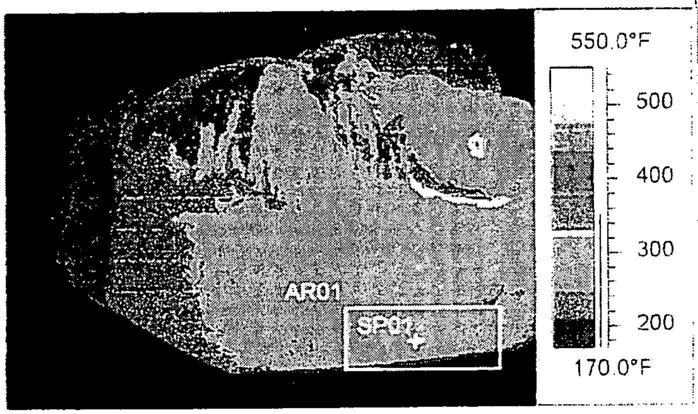
SES Technical, Inc.

Bottle Car Infrared Survey Sheet

December 1, 1998

Ladle Number	Total Tons	Tons on Gun	Status	High Temp	Temp Diff
113	158000	18500	within parameters	329	124

Idle End



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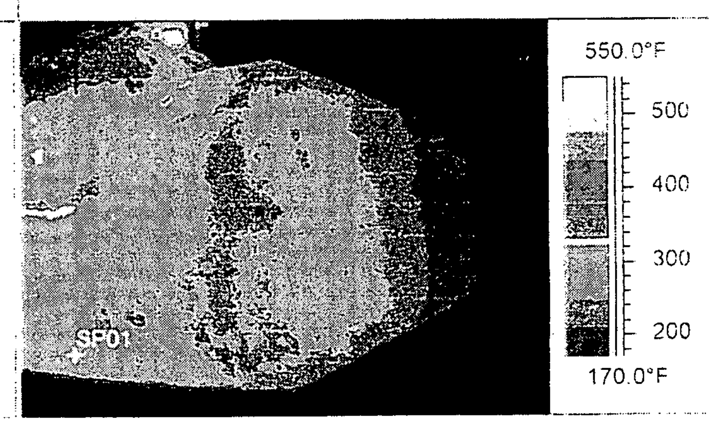

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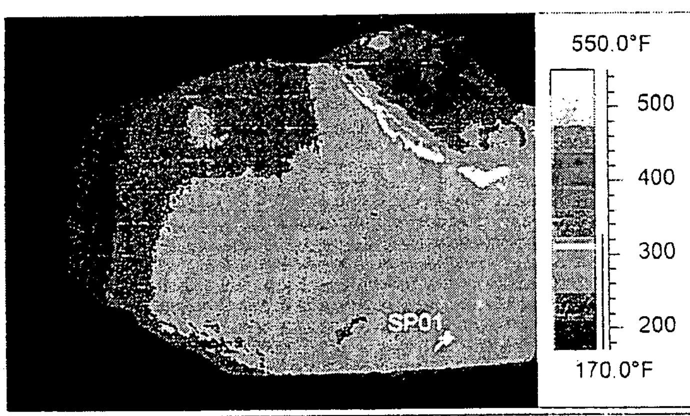

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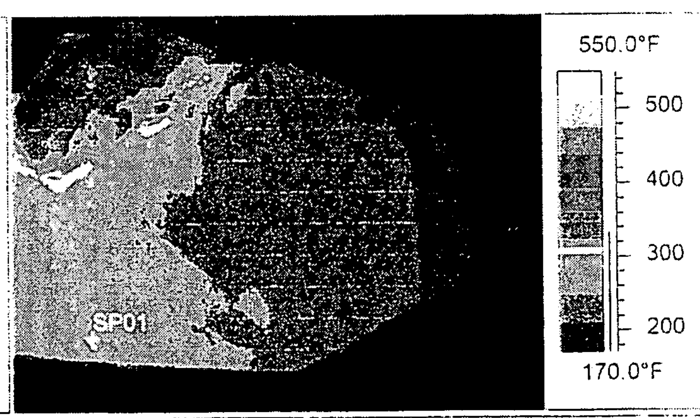

Idle End

Image 6. Sample Report

ACKNOWLEDGMENTS

1. Richard Springsteen, SES Technical, Inc.

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1. Snell Infrared, *Thermographic Applications for Predictive Maintenance*, Montpelier Vermont, 1998.

2. United States Steel Corporation, *The Making Shaping and Treating of Steel*, Eighth Edition, 1964